NACA RM A58E21

N63-12504
Code-1

RESEARCH MEMORANDUM

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A FLIGHT STUDY OF THE EFFECTS OF NOISE FILTERING IN THE ATTACK DISPLAY ON THE PILOT'S TRACKING PERFORMANCE

By Howard L. Turner and Donovan R. Heinle

Ames Aeronautical Laboratory
Moffett Field, Calif.

OTS PRICE
XEROX $ 1.60 ph
MICROFILM $ 0.80 mf

CLASSIFICATION CHANGED TO UNCLASSIFIED - AUTHORITY NASA - EFFECTIVE DATE SEPTEMBER 14, 1962

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON
September 10, 1958

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A FLIGHT STUDY OF THE EFFECTS OF NOISE FILTERING IN THE ATTACK DISPLAY ON THE PILOT'S TRACKING PERFORMANCE*

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SUMMARY

Flight tests were conducted with a director-type radar fire-control system, with scope presentation of the steering information, to determine the effects of attack-display smoothing on the pilot's tracking and steering effectiveness in tail-chase and lead-collision beam attacks.

The pilot manually filtered noise appearing on the attack display when low values of the time constant of the attack-display noise filters were used. As a result, reducing the attack-display time constant from approximately 2 seconds to 0.9 second did not impair his tracking and steering effectiveness. The reduced time constant decreased the inherent time lags in the steering signals presented to the pilot and thereby increased the speed with which the fire-control system indicated steering errors.

INTRODUCTION

Flight investigations of various characteristics of a director-type radar fire-control system in automatic and manually controlled attacks are reported in references 1 to 3. Experience with attack-display steering obtained during these investigations indicated that the amount of noise present on the steering signals shown on the attack display affected the ability of the pilot to track a target effectively. For example, when steering information is computed from noisy radar input signals and is presented, unsmoothed, on an attack display, such erratic steering-dot motions result that the pilot is unable to track effectively. Smoothing the steering signals eliminates the objectionable noise, but only at the expense of introducing undesirable lags between the computed steering signals and those appearing on the attack display. Smoothing of the steering signals also limits the pilot's ability to rapidly detect the build-up of steering errors due to target maneuvers. Thus, the

*Title, Confidential.

selection of smoothing filters for the steering signals represents a compromise between a noisy steering dot and excessive lags in presenting smoothed steering information to the pilot.

The human pilot has a demonstrated ability to change both gain and time constant while engaged in a simple tracking task. These variable human characteristics, discussed at length in references 4, 5, and 6, are of particular interest since the attack-display steering problem, where the pilot concentrates on the motions of a simple steering index, is essentially a simple tracking task. Thus, when the pilot uses his inherent ability to vary his gain and his time constant, a moderately noisy steering dot is not expected to materially impair the over-all tracking performance.

The purpose of this investigation was to determine the minimum amount of steering signal smoothing that would be acceptable to the pilot in representative attack situations. A reduction in the amount of electronic noise filtering, normally included in a fire-control system to provide the pilot with a smooth steering dot, would decrease the inherent lags in the steering signals appearing on the attack display which would, in turn, increase the capability of the pilot to detect and compensate for target maneuvers more rapidly.

EQUIPMENT AND TECHNIQUES

Fire-Control System

For this investigation an E-4 director-type fire-control system was used which presented steering information to the pilot on a 5-inch attack-display oscilloscope. Complete descriptions of this fire-control system are given in references 7, 8, and 9. A typical attack-display circuit diagram is shown in figure 1. All adjustable parameters affecting the motions of the steering dot on the attack display, except the smoothing filters, were held at their design levels except where otherwise noted. In tail-chase attacks the steering-dot sensitivity was equivalent to a projectile time of 4 seconds (ref. 3). In all attacks the steering-dot scale factor was 24 yds/sec/in. (ref. 3). The noise-free static gearing of the steering dot in lead collision maneuvers was 80 mils/in.

Smoothing.- Second-order filters in the azimuth and elevation channels are used to filter radar noise from the steering signals appearing on the attack display. These second-order filters, of the form $1/(1+\tau_1 p)(1+\tau_2 p)$, are composed of two first-order filters in cascade as shown in figure 1. For convenience, the time constant, τ_q, of the first-order approximations of these second-order filters is used to identify the particular filter being studied, that is, the assumption is made that $\tau_q = \tau_1 + \tau_2$. Calculated transient response characteristics shown in figure 2 demonstrate the validity of this assumption. The measured steering-dot transient response characteristics for the various filters are given in figure 3. Data measurements were made at the scope face for a step input into the summing network on the left in figure 1 and include the time lags in the smoothing filters and in the chopper demodulator circuit. The actual values of the filter time constants τ_q, τ_1, and τ_2 and of the components of resistance (R_1, R_2, and R_3) and capacitance (C_1 and C_2) used in these filters are given in table I.

Quick indication.- A typical method used to partially compensate for smoothing lags is to insert a lead term, called "quick indication," into the attack-display circuit in the form of a normal-acceleration signal as shown in figure 1. With this form of quick indication, steering-dot motions due to own-ship motions appear on the attack display without the usual time lag. The method and theory of this form of quickening are discussed in detail in references 7 and 8. For proper compensation, the gain K_q of the normal-acceleration term, A_z, should be adjusted so that the quick-indication lead term, K_qA_z, should exactly cancel the smoothing filter time constant, τ_q. Because of circuitry problems associated with the complexity of the E-4 fire-control system, it was not always possible to obtain values of K_qA_z that would exactly cancel τ_q. However, for the tail-chase and lead-collision attacks used in the present investigation the maneuvers of the aircraft were small, and the effects of incomplete compensation are believed to be negligible.

Test Techniques

Flight tests were conducted in tail-chase and lead-collision beam attacks to obtain tracking characteristics typical of those encountered during the firing of guided missiles or unguided rockets. Maneuvers requiring rapid flight-path changes were not included because inherent limitations in the space stabilization of the radar antenna (ref. 1) made maneuvering data unreliable for comparative purposes.

Tail-chase attacks.- Tail-chase attacks, requiring extreme precision in the control of the aircraft, were conducted at a fixed range of approximately 1000 yards with the test conditions tailored to minimize the dynamic effects of range rate, antenna rates, antenna angles, and steering-dot sensitivities on the behavior of the steering dot. Noise inputs to the fire-control system were assumed to be constant throughout the series of tests. The noise appearing on the attack display was varied by changing the smoothing filters. The root-mean-square (rms) radial gun-line wander was used as a measure of the weapon system effectiveness, and the rms steering-dot wander from the center of the attack display was used as a measure of the pilot's steering effectiveness.

Lead-collision beam attacks.- Lead-collision attacks were conducted with the flight path of the attacker approximately 90° from the flight path of the target. Radar lock-on was obtained at ranges between 12 and 15 miles slant range. In this series of tests the system dynamics and noise effects varied throughout the attack although it was assumed that the variations were similar in all attacks. Gun-line wander was not obtained since the interceptor is only required to be within ±3° in the initial phase, ±1° in the final attack phase, and on target in elevation only in the terminal guidance phase. Pilot's steering effectiveness was indicated by the rms radial steering-dot wander from the center of the steering reference on the attack display in the final attack phase (phase II) and by the rms elevation steering-dot wander in the terminal guidance phase (phase III).

Test Aircraft

The test vehicle used in this study was an F-86D all-weather interceptor. For the tail-chase attacks, F-86A and F-84F airplanes were used as targets, and for the lead-collision beam attacks, a B-47 airplane was used as the target. All flights were conducted at 30,000 feet with a target-interceptor speed ratio of 1:1. The tail-chase attacks were conducted at $M = 0.70$; the lead-collision attacks were conducted at $M = 0.80$.

RESULTS AND DISCUSSION

Tail-Chase Attacks

The effects of attack-display smoothing on the manual tracking characteristics in tail-chase attacks are shown in figures 4 and 5. Abrupt discontinuities in tracking effectiveness data (fig. 4(a)) and in the steering effectiveness data (fig. 4(b)) indicate a possible change in piloting technique when the attack-display smoothing time constants are reduced below 1.32 seconds. Time histories shown in figure 5 indicate that the piloting technique is changed between time constants of 1.32 seconds and 0.86 second.

With a constant noise input to the fire-control system, it is reasonable to assume that the steering-dot wander would increase as the attack-display smoothing time constants are decreased. It is also reasonable to assume that a corresponding increase in gun-line wander would occur as long as the piloting techniques remain the same. The discontinuity in the curves shown in figure 4 occurs when the time constant is sufficiently small that the pilot tends to filter manually by steering to the estimated mean position of the steering dot. The presence of pilot filtering is demonstrated in figure 4 by the fact that the gun-line wander remains fixed while the steering-dot wander increases rapidly (τ_q = 0.86 sec to τ_q = 0.41 sec). The increase in steering-dot wander in this case is the direct result of the increase in noise shown on the attack display as the result of the decrease in the time constants of the smoothing filters. For comparative purposes, the fixed-sight (ref. 3), noise-free, mean gun-line wander, and the estimated[1] equivalent noise-free, mean steering-dot wander are shown in figures 4(a) and 4(b), respectively.

An interaction between own-ship motions and steering-dot motions was noted in reference 1. The pilot attempts to follow a noisy steering dot with control-stick motions to attain the desired tracking precision; this disturbs the radar antenna and produces additional steering-dot motions that can be termed "pilot-induced noise." An example of the results of pilot-induced noise can be seen from a comparison of the time histories of figure 5(a), in which the pilot attempted to follow the noisy steering dot, with the time histories of figure 5(b), in which the pilot filtered manually. The decrease in pilot-induced noise may account for the decrease in gun-line wander and steering-dot wander in figure 4 when the pilot filters manually. The crosshatched area shown in figure 4 indicates the range of time constants where the pilot may or may not be able to follow the instantaneous steering-dot motions.

The results in figure 4 indicate that similar tracking characteristics are obtained when the pilot filters manually (τ_q = 0.86 sec) and when typical values of attack-display smoothing (τ_q = 2.08 sec) are used. This suggests a possible way of decreasing lags in the attack display without impairing system performance. If the pilot filters manually, the attack-display smoothing time constant can be reduced from approximately 2 seconds to 0.9 second. As a result, the time to indicate 95 percent of a steering error would be decreased from 5 to 2 seconds (see fig. 3). Such a decrease in steering signal lag should enable the pilot to detect and correct for target errors more rapidly.

Lead-Collision Beam Attacks

The steering effectiveness data shown in table II and the steering-dot time histories shown in figure 6 were obtained in combat-type lead-collision beam attacks against a B-47 jet bomber. The steering effectiveness data in table II show that the average steering effectiveness

[1]Estimated from steering-dot data obtained with a single corner-reflector target that was considered to be essentially noise free.

in lead-collision beam attacks with an 0.86-second time constant and manual filtering compares favorably with corresponding steering-effectiveness data obtained with a normal 2.08-second attack-display time constant.

The pilot preferred the lower time constant even though the steering dot was noisier than with normal 2.08-second time constant. With the lower time constant, the pilot was able to detect and correct for target errors before the errors built up to the point where large aircraft maneuvers were required. No steering problems associated with the noisy steering dot were reported.

The steering-dot time histories in figure 6(a) show that the pilot has little difficulty in maintaining the noisy steering dot within the boundaries of the reference circles during the attack when an 0.86-second smoothing filter is used. Figure 6(b) illustrates how an error can develop during the final attack phase (phase II) which cannot be corrected during the terminal guidance phase (phase III) because of lags in the attack display due to the 2.08-second smoothing time constant. Errors of this type were not obtained when the 0.86-second attack-display time constant was used. Improved terminal guidance can be expected with a lower attack-display time constant.

The pilot's ability to filter manually permits the use of a low attack-display time constant without causing the tracking and steering effectiveness to deteriorate. This can result in an earlier detection of target motions and hence an increased probability of a successful attack. Such an increase in the ability to detect target motion may be advantageous in attacks on maneuvering targets.

SUMMARY OF RESULTS

Flight tests were conducted to examine the effects of attack-display smoothing on the pilot's tracking and steering effectiveness in mild maneuvers associated with tail-chase tracking and with the final phases of lead-collision beam attacks. The results indicated that the pilot can manually filter noisy steering information and therefore the built-in time lags in attack-display steering information can be reduced. The pilot's steering effectiveness with an 0.86-second attack-display time constant and a noisy steering dot compared favorably with the steering effectiveness obtained with a 2-second attack-display time constant and a smooth steering dot. In lead-collision beam attacks, terminal guidance was improved with the reduced time constant.

Reducing the time constant of the attack-display smoothing filters from 2.08 seconds to 0.86 second decreased the inherent lags due to smoothing. The resulting increase in the capability of the pilot of a manually operated interceptor to detect target motions more rapidly increases the possibility of a successful attack. The increase in the ability to detect target motion may be advantageous in attacks on maneuvering targets.

Ames Aeronautical Laboratory
National Advisory Committee for Aeronautics
Moffett Field, Calif., May 21, 1958

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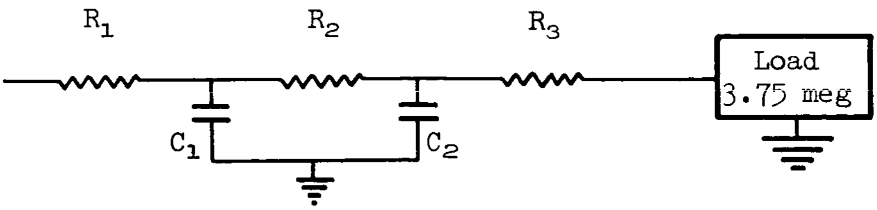
TABLE I.- FILTER PARAMETERS



R_1 meg	R_2 meg	R_3 meg	C_1 mfd	C_2 mfd	τ_1 sec	τ_2 sec	τ_q sec
0.50	1.57	0	0.27	0.215	0.32	0.09	0.41
.50	1.33	.25	1.27	.214	.19	.67	.86
.50	1.59	0	2.08	.275	.28	1.04	1.32
.50	1.00	.59	2.00	1.00	.48	1.60	2.08
.50	1.04	.55	1.58	1.76	.48	2.30	2.78
.50	1.29	.327	1.48	1.99	.50	2.70	3.20

TABLE II.- STEERING EFFECTIVENESS IN LEAD-COLLISION BEAM ATTACKS

Target: B-47 at M = 0.80, 30,000 ft

Interceptor: F-86D at M = 0.80, 30,000 ft

rms steering-dot wander phase II (radial)		rms steering-dot wander phase III (elevation only)		Filter time constant, τ_q
in.	yd/sec	in.	yd/sec	sec
0.140	3.38	0.038	0.92	0.86
.121	2.92	.029	.70	.86
.239	5.76	.125	3.02	.86
.210	5.06	.111	2.68	.86
.364	8.78	.096	2.32	.86
.226	5.45	.014	.34	.86
Average .216	5.23	.069	1.66	
.157	3.78	.035	.85	2.08
.212	5.11	.079	1.90	2.08
.181	4.36	.196	4.72	2.08
.188	4.54	.038	.92	2.08
.222	5.35	.088	2.12	2.08
.162	3.91	.188	4.54	2.08
Average .171	4.52	.103	2.14	

Note: All tracking performance data listed above were measured from filtered steering signals at the scope face. Measurements were made from center of steering reference.

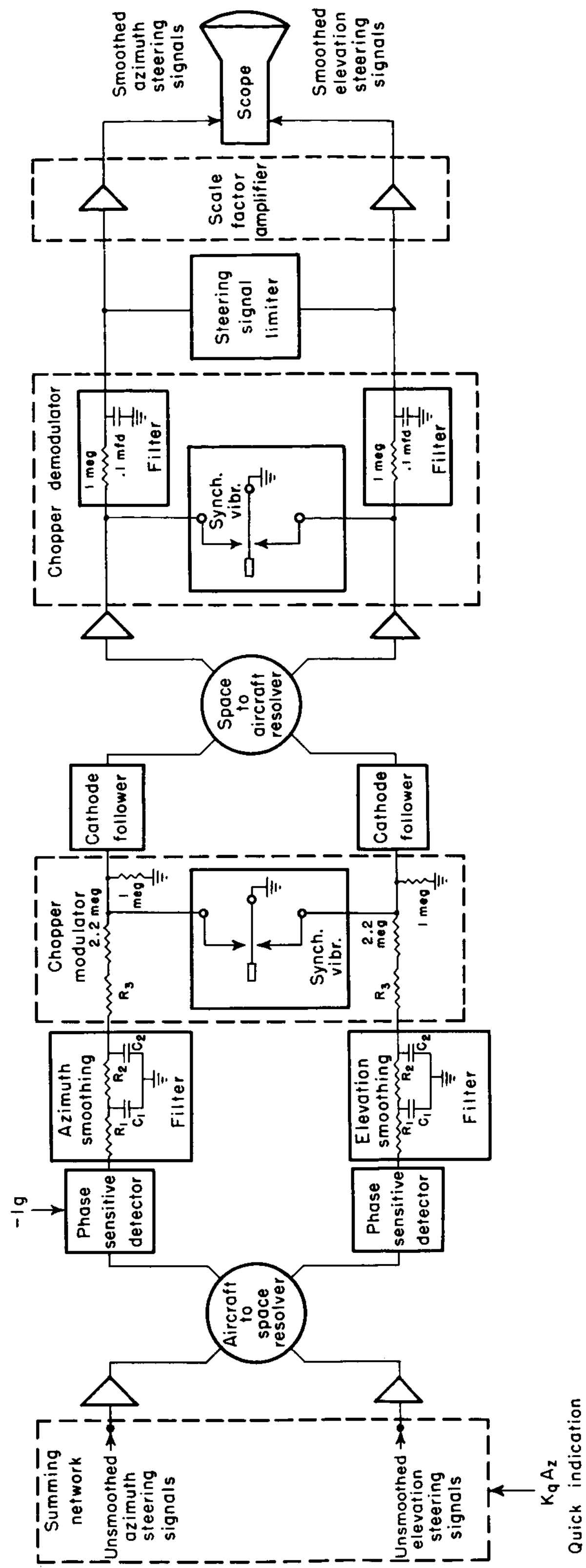


Figure 1.- Typical attack-display circuit.

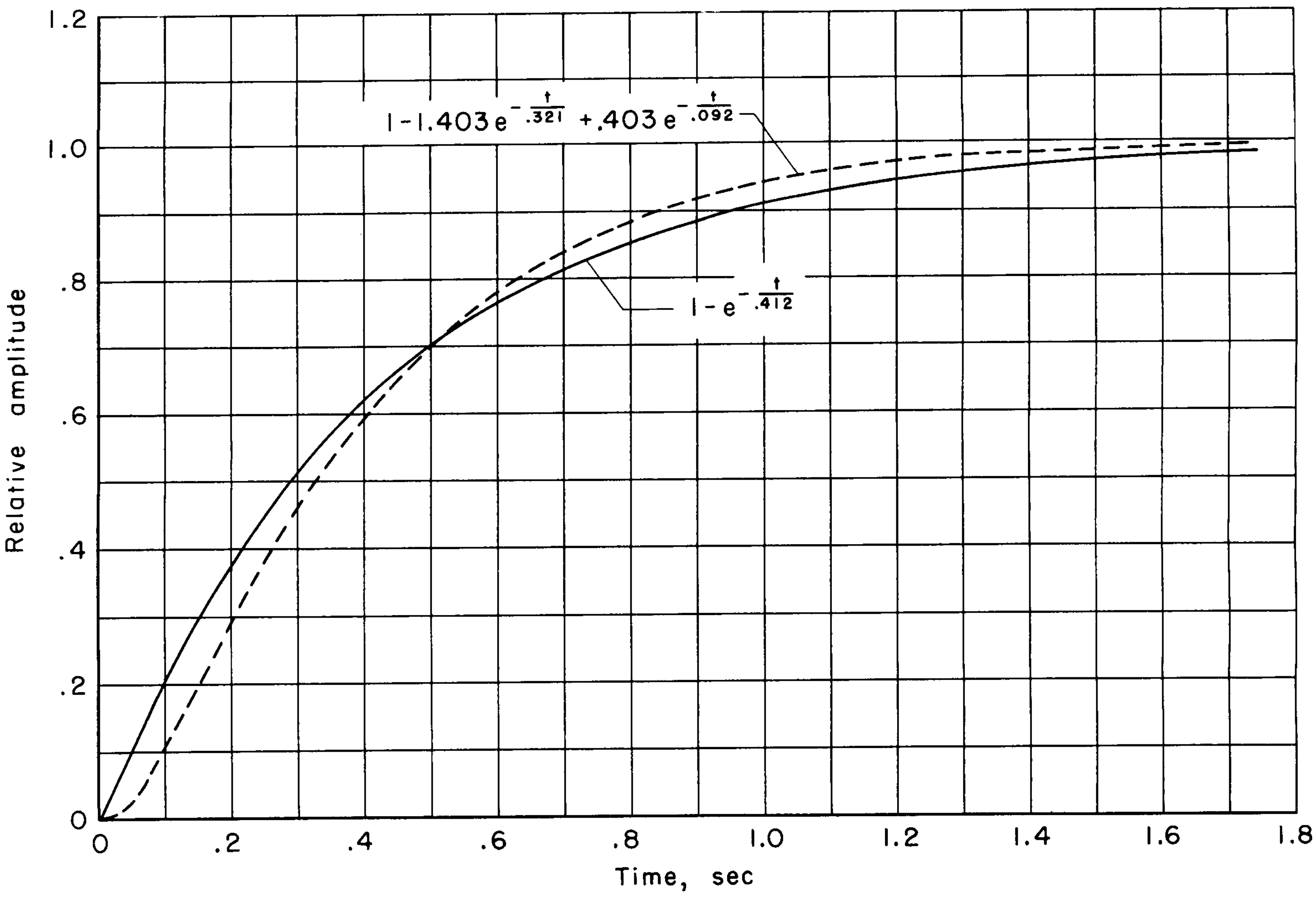


Figure 2.- Comparison of calculated transient responses using second-order filter and first-order approximation of second-order filter.

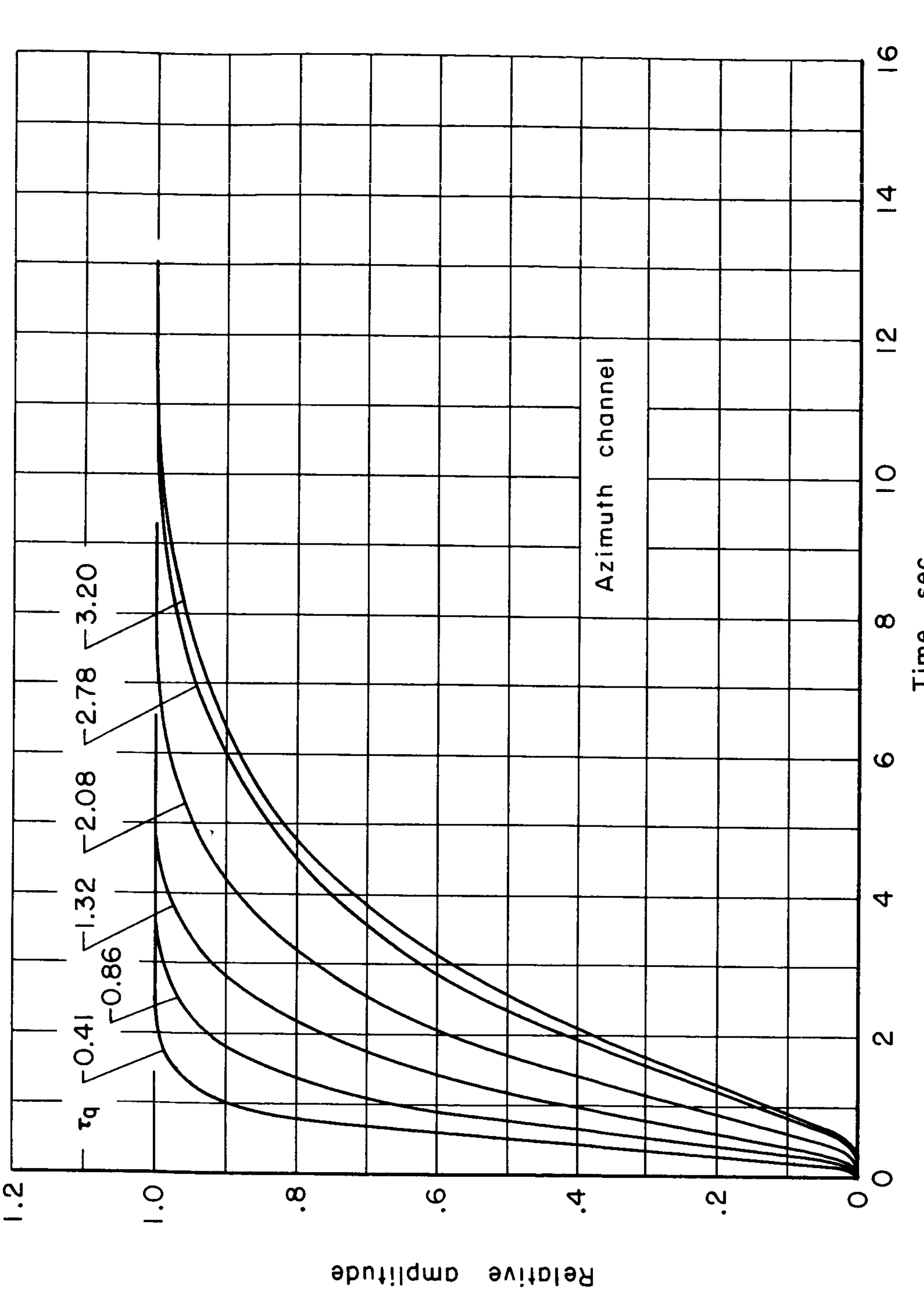
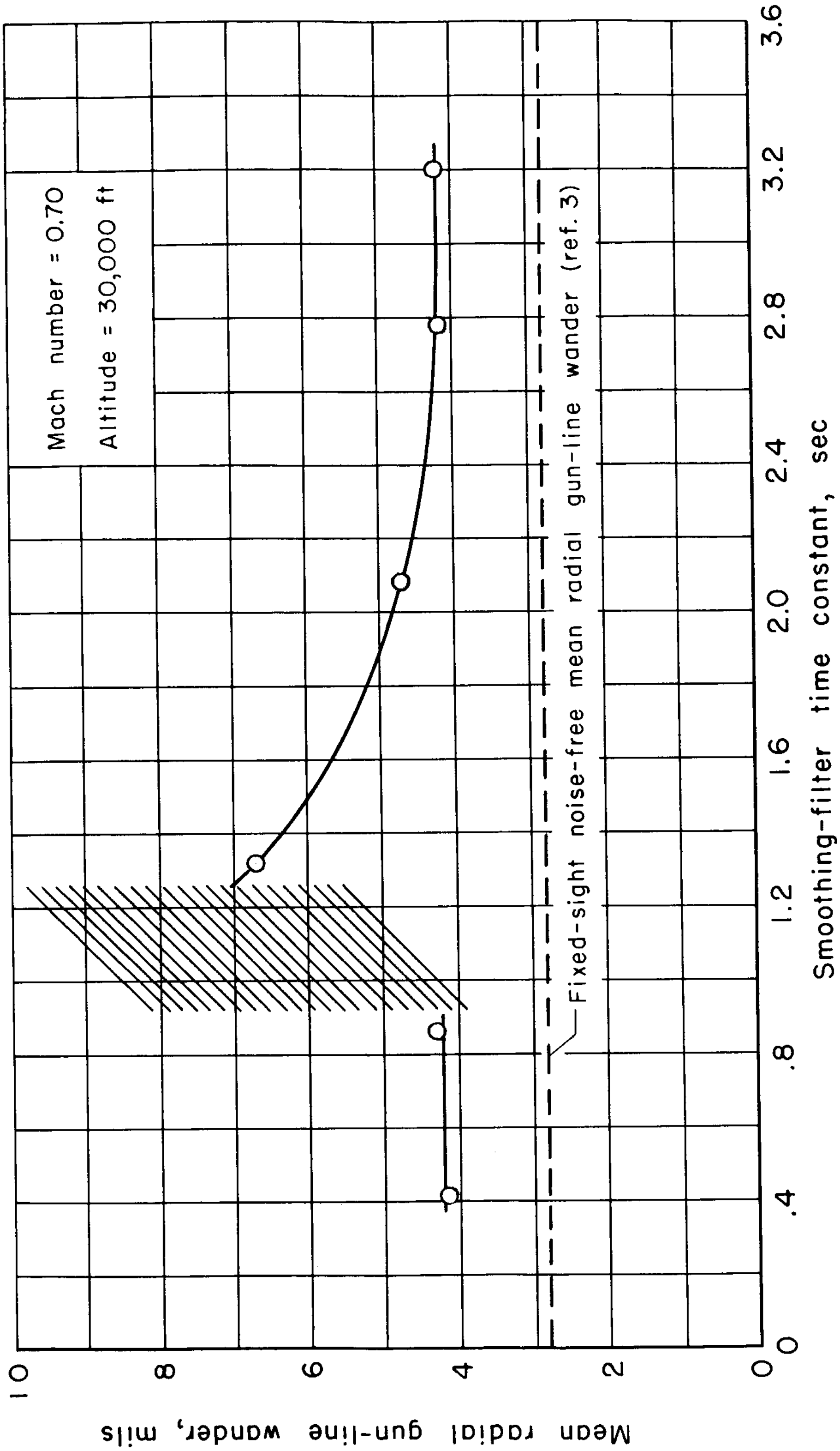
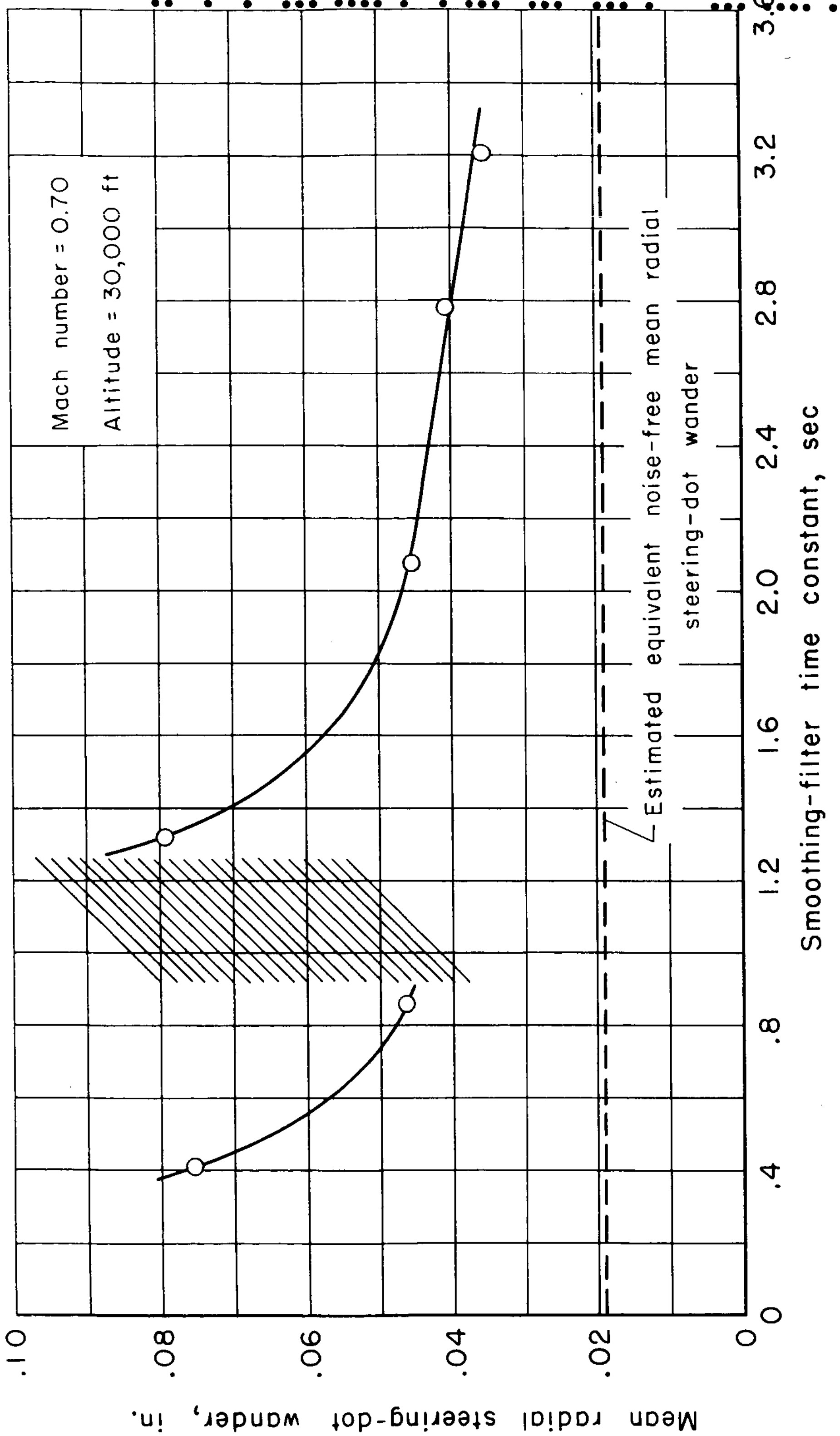


Figure 3.- Steering-dot transient-response characteristics measured at the face of the attack display.



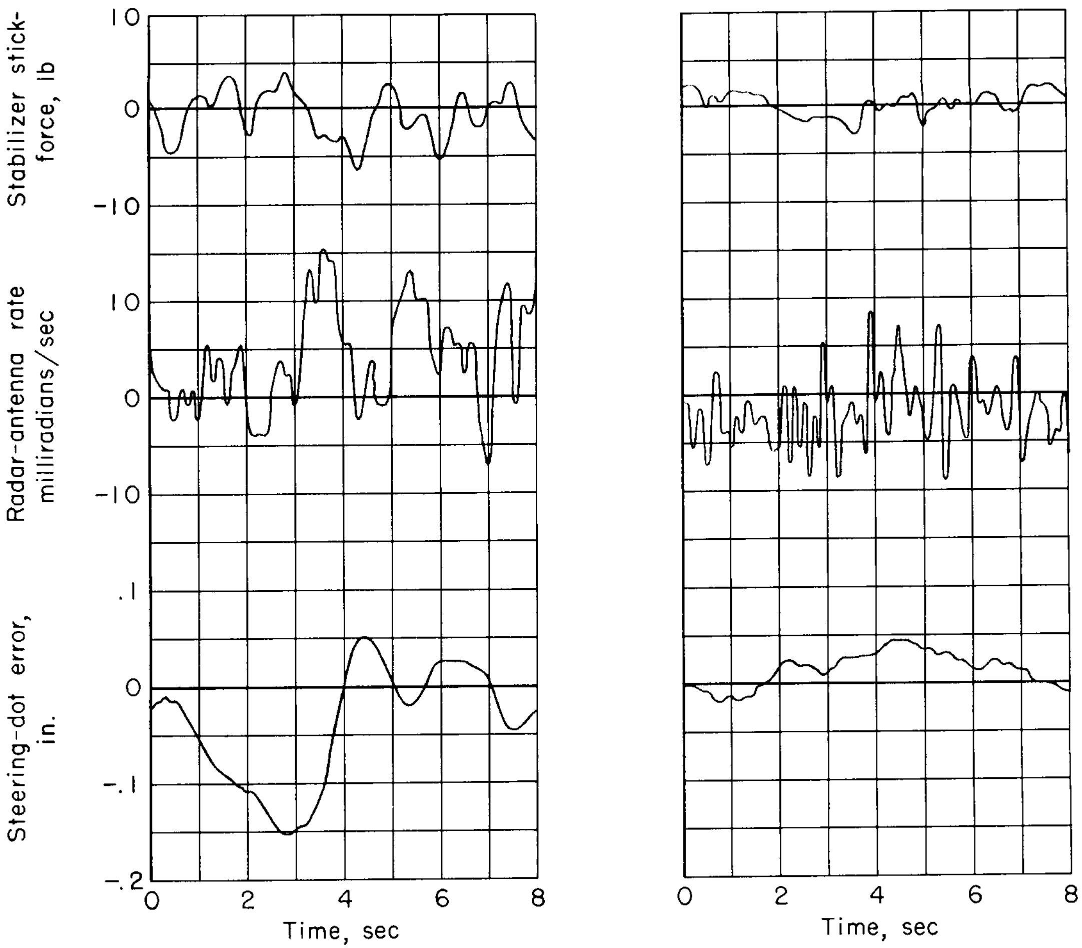
(a) Tracking effectiveness.

Figure 4.- Effects of attack-display smoothing on the manual tracking characteristics in a tail-chase attack.



(b) Steering effectiveness.

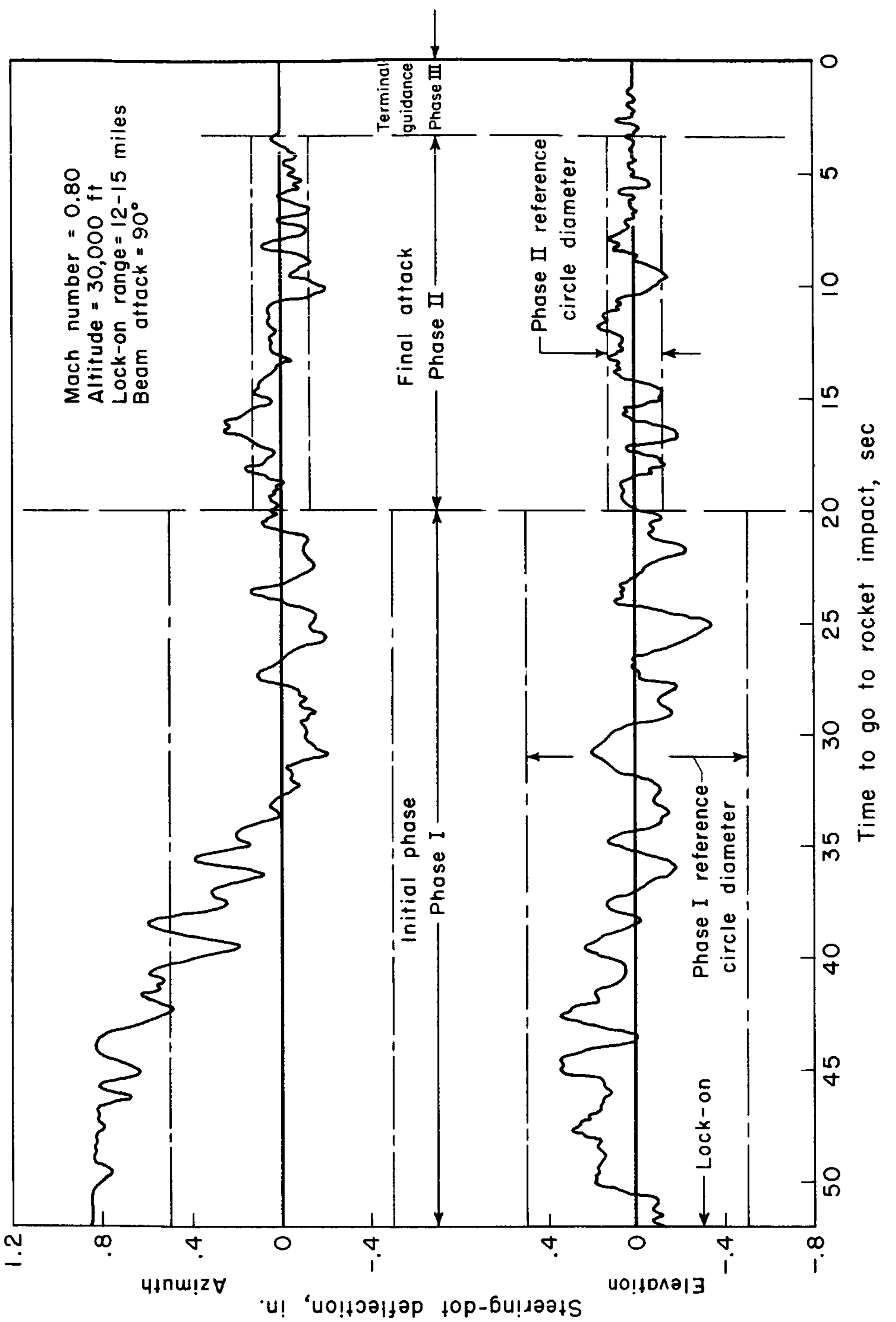
Figure 4.- Concluded.



(a) τ_q = 1.32 seconds

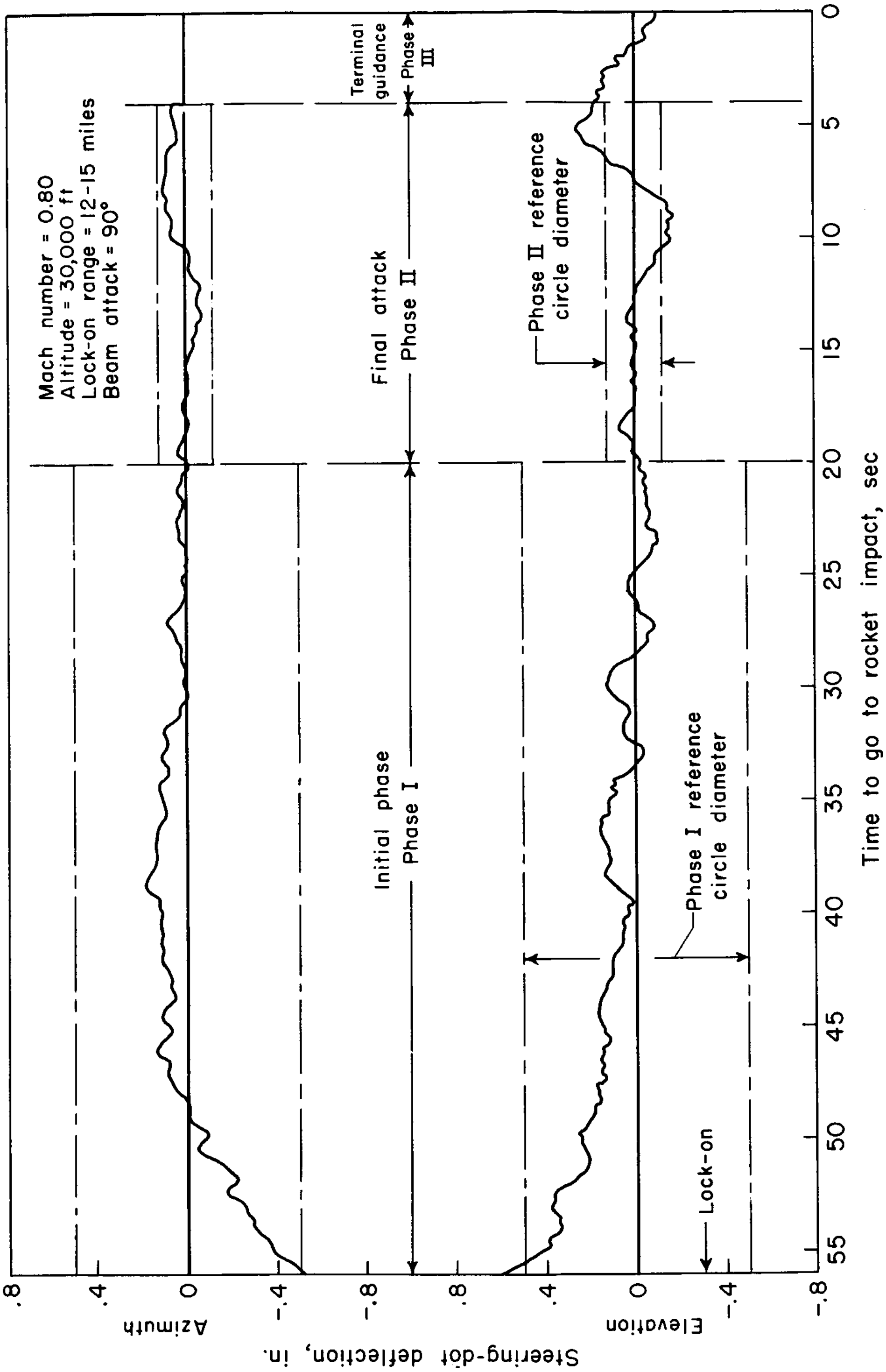
(b) τ_q = 0.86 second

Figure 5.- Time histories of airplane flight-control and fire-control system parameters taken during steady, wings level, tail-chase attacks.



(a) $\tau_q = 0.86$ second

Figure 6.- Time histories of steering-dot deflections in manually controlled lead-collison beam attacks, tracking through an attack display.



(b) τ_q = 2.0 seconds

Figure 6.- Concluded.

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